Physics at a Photon Collider

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A Photon Collider will provide unique opportunities to study the SM Higgs boson and to determine its properties. MSSM Higgs bosons can be discovered at the Photon Collider for scenarios where they might escape detection at the LHC. As an example for the many other physics topics which can be studied at a Photon Collider, recent results on Non-Commutative Field Theories are also discussed.

1. Introduction

The Photon Collider option of a Linear Collider (LC) is based on laser photon back-scattering on high energy electrons. The maximum photon energy is 205 GeV for a laser with $\lambda = 1.06\mu$m and an electron beam energy of 250 GeV. A high degree of polarisation with opposite helicities of the electron and the laser photon is crucial for obtaining a peaked spectrum of high energy polarised photons close to the maximum energy. In this case the high energy part of the $\gamma\gamma$ spectrum is dominated by the spin-0 configuration which is important to enhance the signal and suppress the background for Higgs production. Alternatively, eγ interactions are also possible. The technical aspects of the photon collider are discussed in [1,2].

2. Higgs Production

Neutral Higgs bosons are produced in the scattering of two photons as a s-channel resonance through a loop. In this loop all charged particles contribute which obtain their mass from electroweak symmetry breaking. The two-photon partial width of the Higgs boson is therefore sensitive to physics beyond the SM.

For Higgs bosons decaying predominantly into b$\overline{\mathrm{b}}$, the main source of background are $\gamma\gamma \to \mathrm{Q}\overline{\mathrm{Q}}$ processes (Q=c,b). The spin-0 component of these processes is suppressed in Leading Order (LO) by a factor m_Q^2/s. Since this suppression is only valid in LO, a realistic background simulation should be based on a next-to-leading (NLO) calculation.

Several analyses of H $\to$ b$\overline{\mathrm{b}}$ decays for a SM Higgs boson in the mass range from 120 GeV to 160 GeV have been performed [3,4]. All analyses exploit the kinematic differences between the s-channel signal and the t-channel background by cutting on visible energy and angular distributions. The results are shown in Fig. 1.

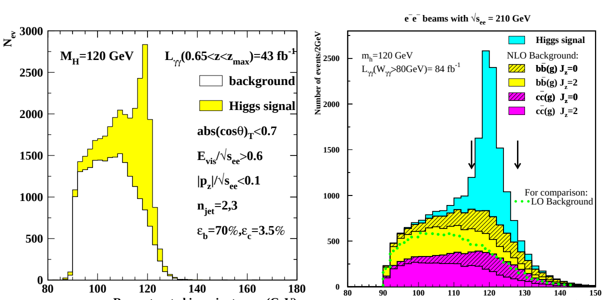

Figure 1. Reconstructed invariant mass for a Higgs boson mass of 120 GeV with the full NLO background simulation. The detector response is simulated with SIMDET. Left plot from [3] and right plot from [4].

Before b-tagging the ratio of background from $\gamma\gamma \to$ c$\overline{\mathrm{c}}$ events to $\gamma\gamma \to$ b$\overline{\mathrm{b}}$ events is approximately 16 due to the quark charges. Excellent

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b-tagging is therefore required to suppress the charm background. The need to minimize the radius of the beam pipe is one of the main challenges for a Photon Collider, since the beam pipe has to accomodate the optical system for producing back-scattered photons.

The analyses presented here have assumed that $\mathrm{b\overline{b}}$ events are tagged with 70% efficiency and $\mathrm{c\overline{c}}$ events with 3.5% efficiency. For a luminosity corresponding to roughly one year of running, a statistical uncertainty of about 2% for a Higgs mass of 120-140 GeV for the two photon width measurement can be achieved. The uncertainty increases to about 10% for a Higgs mass of 160 GeV.

At Higgs boson masses above 160 GeV decays into WW and ZZ pairs become important. In this case the interference between signal and $\gamma\gamma \rightarrow$ WW background needs to be taken into account. The interference gives access to an additional observable, the phase $\phi_{\gamma\gamma}$ of the $\gamma\gamma \rightarrow$ H amplitude. The combined precision of phase and partial width determination gives sufficient precision to distinguish the SM from SM-like 2HDM (II) scenarios [5]. The results of a detector simulation are shown in Fig. 2.

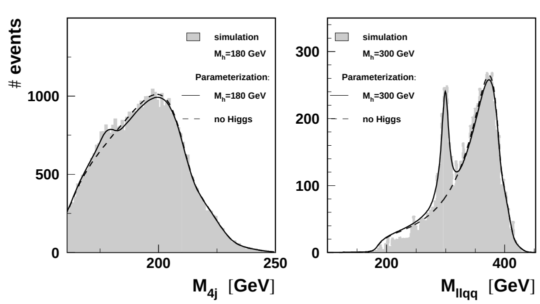

Figure 2. Reconstructed invariant mass for $\gamma\gamma \rightarrow WW$ events with a SM Higgs mass of 180 GeV (left) and for $\gamma\gamma \rightarrow$ ZZ events with a SM Higgs mass of 300 GeV (right) [5].

The neutral MSSM Higgs Boson H,A for masses above 200 GeV and for moderate $\tan\beta \approx 7$ might escape detection at the LHC. In this parameter region, where decays into $\mathrm{b\overline{b}}$ are the dominant SM decays up to Higgs masses around 550 GeV, the Photon Collider can discover the neutral MSSM Higgs Bosons [6]. In contrast to the $\mathrm{e^+e^-}$ option of the LC, the Photon Collider can produce these Higgs Boson with masses up to about 80% of $\sqrt{s}_{\mathrm{ee}}$. Cross-sections for signal and background are shown in Fig. 3.

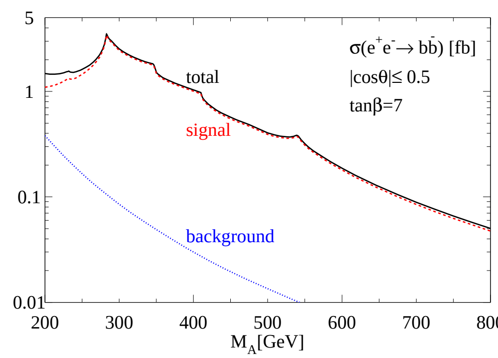

Figure 3. Cross-section for the process $\gamma\gamma \rightarrow$ A $\rightarrow \mathrm{b\overline{b}}$ and for the background $\gamma\gamma \rightarrow \mathrm{b\overline{b}}$. A mass window of ± 3 GeV has been applied, 100% polarisation is assumed, and only the two-jet configuration is considered [6].

Many other Higgs scenarios have been studied for the Photon Collider option, adding to the discovery potential: For example, the measurement of CP properties of the Higgs bosons A,H in $\mathrm{t\overline{t}}$ decays [7] or the production of charged Higgs bosons in the process $\gamma\gamma \rightarrow \mathrm{H^+H^-}$ [8].

3. Non-Commutative Field Theories

One of many other interesting topics which can be studied at a $\gamma\gamma$ or at an $\mathrm{e}\gamma$ collider are non-commutative quantum field theories (NC-QFT) with non-commuting (NC) space-time operators [9]. The additional cubic coupling $(\gamma\gamma\gamma)$ contributing to the process $\gamma\gamma \rightarrow \mathrm{f\overline{f}}$ is shown in Fig. 4.

The parameter Λ_{NC} characterises the threshold where NC effects become relevant. The current

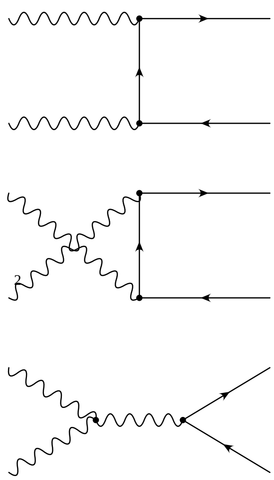

Figure 4. Diagrams contributing to fermion pair production ($\gamma\gamma \rightarrow \mathrm{f\bar{f}}$) in NCQFT.

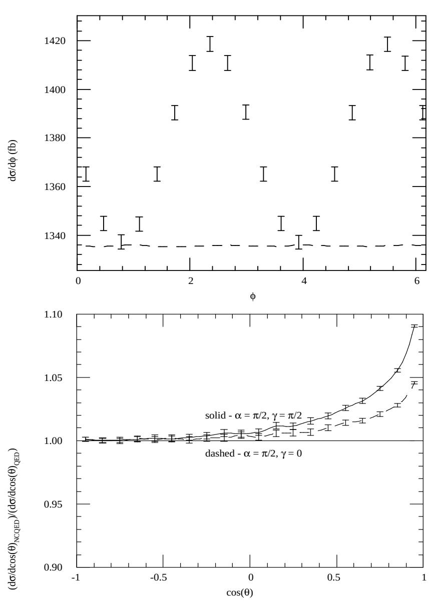

Figure 5. $\mathrm{e}\gamma \rightarrow \mathrm{e}\gamma$ scattering at $\sqrt{s}_{ee} = 500$ GeV a) Differential cross-section $\mathrm{d}\sigma/\mathrm{d}\phi$ for the SM (dashed line) and for $\Lambda_{\mathrm{NC}} = 500$ GeV ($\alpha = \gamma = \pi/2$). The expected statistical uncertainties are also shown. b) Ratio of the differential cross-sections $\mathrm{d}\sigma/\mathrm{d}\cos\theta$ for NCQFT and for the SM.

limit from $\mathrm{e}^+\mathrm{e}^-$ scattering is $\Lambda_{\mathrm{NC}} > 142$ GeV at 95% confidence level [10].

A theoretical analysis has been performed of the processes $\gamma\gamma \rightarrow \mathrm{f\bar{f}}$ and $\mathrm{e}\gamma \rightarrow \mathrm{e}\gamma$ for $L_{\mathrm{ee}} = 500\ \mathrm{fb}^{-1}$. A transverse momentum greater than 10 GeV and a polar angle in the range $10^\circ < \theta < 170^\circ$ has been required for the final state particles.

In Fig. 5 the NCQFT effects on the angular distributions of the final state photons in $\mathrm{e}\gamma \rightarrow \mathrm{e}\gamma$ scattering are shown. The parameters α and γ are related to the Maxwell field tensor [9]. Significant deviations from the SM can be observed.

4. Conclusion

Studies of various Higgs scenarios show that a Photon Collider has a unique potential for Higgs boson physics over a wide range of masses and model parameters. Excellent b-tagging and good energy resolution are very important for the Photon Collider to suppress background. The $\mathrm{e}\gamma$ option of the Photon Collider is complementary to the $\mathrm{e}^+\mathrm{e}^-$ Linear Collider in discovering effects from Non-Commutative Field Theories. Many other topics which can be studied at a Photon Collider (e.g. SUSY, Leptoquarks, QCD) had to be omitted in this short summary.

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